

Measurement of *in situ* Acoustic Properties for the ONR Geoclutter Program

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LONG-TERM GOALS

The long-term objective of the GEOCLUTTER program is to understand the causes and implications of geologic clutter (reverberation) in a geologically well-characterized shallow-water environment. The field area selected for the GEOCLUTTER program is the mid-outer continental shelf off New Jersey, USA. The New Jersey margin was chosen for the GEOCLUTTER study because the bathymetry and portions of the shallow subsurface of this area had already been mapped in detail as part of an earlier ONR program aimed at understanding the origin of subsurface stratigraphy on continental margins (STRATAFORM). In addition to multibeam bathymetry, 'calibrated' backscatter data (at 95 kHz from the multibeam sonar) was also collected as part of the STRATAFORM program.

SCIENTIFIC OBJECTIVES

The overall scientific objectives of the GEOCLUTTER program are: 1) to understand, characterize, and predict lateral and vertical, naturally-occurring heterogeneities that may produce discrete acoustic returns at low grazing angles (i.e., "geologic clutter") and then; 2) to conduct precise acoustic reverberation experiments at this site to understand, characterize, and potentially mitigate the geologic clutter.

APPROACH

In order to meet these objectives and to properly implement acoustic models for the GEOCLUTTER area, we need to know, or predict, the key acoustic and physical properties throughout the volume of interest (i.e., grain size, density, sound speed, attenuation). The properties of the near-surface seafloor sediments are particularly important. A possible approach to this problem is to use the 95-kHz multibeam backscatter data collected in the region, which may provide information on seafloor sediment properties. If remotely-sensed backscatter data can be used to infer seafloor sediment properties, we would have the ability to make quantitative statements about seafloor properties over large areas of the seafloor and thus the ability to address a number of important navy-related problems. The relationship between backscatter and sediment properties remains ambiguous however, and cannot yet be used as a direct and quantitative predictor of seafloor properties. Attempting to understand the relationship between the multibeam backscatter and the properties of the seafloor is the primary theme of this component of our GEOCLUTTER research program.

In light of the fact that we have not yet successfully been able to produce accurate estimates of seafloor properties from remotely sensed acoustic data, our initial proposal fell back on more traditional means

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of sampling and laboratory measurements to obtain the needed seafloor property information in the GEOCLUTTER area. Given the coarse-grained, sandy nature of the sediment in the region we were concerned that laboratory measurements of certain properties (in particular sound speed and attenuation) on core samples would not reflect *in situ* values as sandy sediments tend to de-water very quickly. Thus, the first phase of our GEOCLUTTER work consisted of the development of a simple and relatively inexpensive device designed to measure, *in situ*, the spatial variability of sound speed and attenuation in near-surface sediments at the GEOCLUTTER site. Our *in situ* measurements could then be combined with the data collected from cores (by other investigators – John Goff from the University of Texas and Chris Summerfield from The University of Delaware) as well as other acoustic data (experiments by Charles Holland from Univ of Pennsylvania and Steve Schock at Florida Atlantic University) to better understand the variability of *in situ* sediment physical and acoustic properties in the GEOCLUTTER area.

WORK COMPLETED TO DATE

In support of the Geoclutter program, we have developed, built, and deployed a relatively inexpensive, robust, small-ship-deployable device (**ISSAP – In situ Sound Speed and Attenuation Probe**) for measuring sound speed and attenuation in near-surface sediments. Our objective was to design and deploy a device that would specifically address the question of the spatial variability of seafloor sediment properties by rapidly making multiple measurements of sound speed and attenuation in near-surface sediments. Our concept was to design an instrument that was like a box-corer and that could rapidly make multiple measurements of *in situ* properties by simply “pogo-ing” on the bottom and thus cover a relatively large area of the seafloor in a short period of time. Measurements of *in situ* acoustic properties are particularly critical in the sandy sediments off New Jersey as these sediments tend to quickly dewater making laboratory measurements difficult.

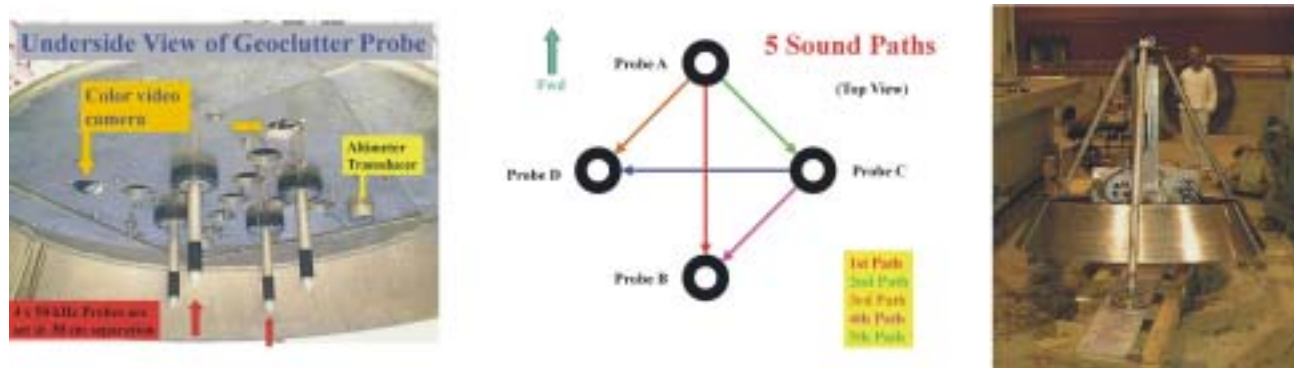


Fig 1. Underside view of ISSAP showing orientation of probes (left), diagram showing 5 paths used for sound speed and attenuation measurement (middle) and photo of tripod and probe assembly (right).

The **ISSAP** uses four 2.54 cm (diameter) by 30 cm long probes that are inserted 15 cm into the seafloor by 250 kg of reaction weight attached by armored coaxial cable to a free-swinging inner frame within a protective outer tripod. This design, in combination with articulated tripod feet, allows the probes to be inserted vertically on slopes up to 20 degrees (Fig 1). The transducer probes are mounted

on an inner frame assembly through precision-machined DelrinTM collars designed to decouple the acoustic signals from the frame. The probes operate at frequencies of either 65 or 100 kHz (all measurements reported here are at 65 kHz). Probe separation can be adjusted in 10 cm increments from 10 to 60 cm. For this study the probes were arranged in a square pattern with nominal path separations of 20 and 30 cm (Fig. 1). An onboard computer and topside electronics control the paths selected and the number of measurements per path. A typical deployment involves measurements across five paths including both long (30 cm) and short (20 cm) paths. In addition to the acoustic probes, the ISSAP also has a color video camera that provides imagery of the seafloor and the probes as they penetrate, a 65 kHz altimeter to independently monitor height off the bottom, and temperature, pressure, pitch, roll, and heading sensors to monitor the stability and orientation of the platform. Finally, a bottom sense switch provides yet another indication of the platform's height above the bottom.

The system is lowered to the bottom on a coaxial cable until the altimeter, bottom sense switch, and camera indicate proximity to the bottom. When the bottom is in sight, a bottom-water measurement cycle is initiated with a short (40 microsecond) pulse transmitted from one of the probes and received by another. Ten measurements are made over each path for a total of 150 measurements in a measurement cycle. Upon completion of the bottom-water measurement cycle the system is lowered into the seafloor where two measurement cycles of 150 measurements each over the 5 paths are made in the sediment. When both sediment measurement cycles are complete, the system is pulled out of the seafloor and another bottom-water measurement cycle is completed. A sampling station thus typically consists of two bottom-water cycles and two sediment cycles with a total of 600 independent measurements of acoustic travel time over 5 independent paths with different separations. Each measurement cycle takes less than one minute; sampling an entire station thus takes on the order of five minutes to complete.

The transmit and receive pulse for each measurement is sent up the coax and digitized at 2 MHz on the topside acquisition computer and sent to a processing computer. An entire measurement cycle (150 measurements) results in approximately 75 Mbytes of data; a typical station (2 bottom-water and two sediment cycle) produces about 300 Mbytes of data. The fundamental measurement is that of the travel time (time-of-flight) between the transmit and received pulse. Travel times are determined by several methods and converted to sound-speed through a calibration process. The details of the analytical procedures are presented in Kraft et al. 2002. There are two levels of calibration available. The most precise involves collecting data in distilled water at a known temperature and using the well-established variation in sound speed with temperature to precisely determine the separation of each pair of transducers. This is done at the beginning of the cruise, at the end of the cruise, and several times during the cruise. We also carry out an ongoing calibration by measuring the speed of sound in seawater (at known temperature) before and after each penetration into the seafloor. Bottom-water calibrations also allow us to determine if the insertion of the probes into the bottom resulted in a change in their relative path length.

Along with measurement of time-of-flight (and thus sound speed) we can also compare the digitized sediment and water path pulses in order to measure sediment attenuation. Several approaches have been used to measure attenuation. The relative amplitude of the received waveforms over the different path-lengths is one indication of attenuation as is the spectral ratio (or difference) between the seawater received waveform and the sediment received waveform. We also use the filter correlation technique of Courtney and Mayer (1993) that was developed especially for short time series of the type we are measuring. The details of attenuation processing are presented in Kraft et al.(2002).

RESULTS

The ISSAP was deployed in the GEOCLUTTER area off New Jersey on the *R/V Cape Henlopen* between 30 July and 5 August, 2001. The system performed flawlessly recovering water column and sediment data at 99 stations selected to represent a range of seafloor backscatter types over an area of approximately 1300 sq. km. More than 40 gigabytes of digital data were collected as well as more than 20 hours of video. A full discussion of the system deployment and initial results can be found in Mayer et al., (2002).

With rare exception, the waveforms recovered from the ISSAP were remarkably clean, allowing not only an unambiguous measurement of time-of-flight but also for the calculation of attenuation (Kraft et al. 2002). Most importantly, the tremendous redundancy of our measurements at each station (typically 300 measurements in the sediment and 300 measurements in the water column) allows us to put well-grounded confidence limits on our measurements and thus understand the true local variability of sound speed and attenuation in the GEOCLUTTER area.

More than 58,000 individual measurements were made over the 1300 sq. km area. The overall accuracy of measurements was ± 1 to 2 m/sec for sound speed and ± 1 dB/m for attenuation. Across the entire area the mean speed of sound in seawater was 1500.8 m/sec with a range of less than 10 m/sec, within the expected change due to variations in bottom-water properties. These values indicate that the system geometry remained constant and the timing precise throughout our operations. In contrast to the consistency of the water column, real and substantial variations in seafloor sound speed and attenuation were measured. The system was deployed in sediments ranging from muddy, silty sands, to gravels and shell hash deposits, with a video record of each deployment providing an indication of the degree of penetration of the probes as well as the nature of the surface sediment. In addition, a grab sample was collected at each station; grain size analyses have been made by scientists from the University of Texas and are discussed in Kraft et al. 2002.

Over the 1300 sq km area, the sound speed in the sediment varied from 1524 m/sec to 1801 m/sec and attenuation ranged from 10 to 71.3 dB/m at 65 kHz. Looking at the spatial scales of variability, we found sound speed varying over 200 – 300 m/sec and attenuation varying by about 60 dB/m over length scales of 10's of kms; sound speed varied by about 100 m/sec and attenuation by about 25 dB/m over spatial scales of less than 1 km (Fig 2) and; sound speed varied by about 5 m/sec and attenuation by about 3 dB/m over spatial scales of less than 1 meter (except where there were discrete shells or cobbles in the path).

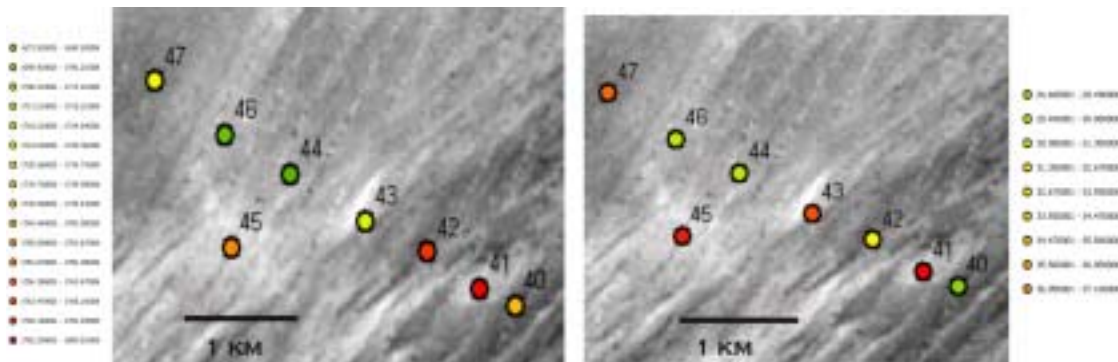


Figure 2. Close-up of sound speed (left) and attenuation (right) at a series of stations superimposed on multibeam sonar backscatter data.

Most often, the geotechnical parameter expected to exhibit some correlation with the attenuation coefficient, $k = \alpha / f$ (in units of dB/m-kHz) is the mean grain diameter. Samples collected by investigators at the Universities of Texas and Delaware were used for a preliminary comparison of attenuation and grain size. Station data, including grain size distributions, were sorted into descending order based on the average attenuation coefficient and divided into groups representing 0.1 dB/m-kHz decreases in attenuation. An average grain size distribution (in % fraction of sample based on weight) representing each group was determined using the grain size distributions of each station in the group.

Although preliminary, the averaged grain size distributions show interesting results (Fig 3). The group of stations with the highest attenuation coefficients ($k = 0.8 - 0.9$ dB/m-kHz), had the largest weight percent of fine sand (.175 to .25 mm) as well as a higher percentage of coarse grains with diameters greater than 4 mm. The group of stations with slightly lower attenuation coefficients ($k = 0.7 - 0.8$ dB/m-kHz), had the second largest weight percent of fine sand, the highest weight percent of grains with diameters < 4 mm, and the highest weight percent of fine grained sediments, those with diameter < 0.062 mm. In contrast, the stations with the lowest attenuation coefficients had the highest weight percent of medium sand (.25 to .35 mm). These stations had grain size distributions indicating relatively, well-sorted sediments (mostly homogeneous, medium grained sands), while the high-attenuation stations contained a mixture of coarse and fine grained sediments.

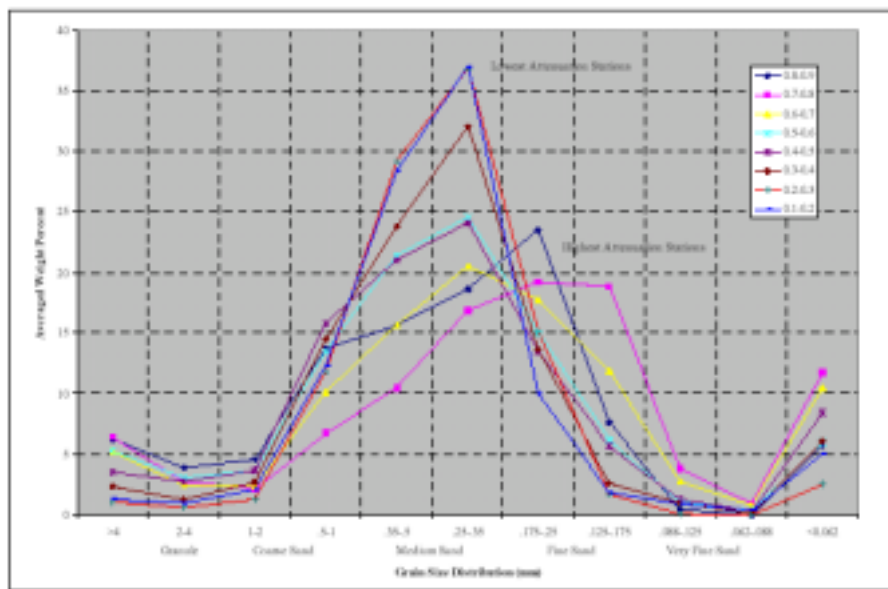


Figure 3. Averaged grain size distributions based on weight percent for each group of stations corresponding to the averaged attenuation coefficient for each station. Distributions show that well sorted sediment appears to have lowest attenuation while poorly sorted sediment appears to have highest attenuation

IMPACT/APPLICATIONS

The ISSAP has provided a simple and quick way to establish the lateral distribution of sound speed and attenuation variations within the Geoclutter area. These measurements are being compared directly to backscatter values from the multibeam system and to the predictions of impedance and attenuation

made from the Chirp Sonar by Schock. They also provide information on the range of natural variability that is very relevant to other Navy programs (e.g., Capturing Uncertainty DRI). The system has also been requested for deployment at the Martha's Vineyard Mine Burial Program field site.

The work described above will play a key part in the overall development of robust seafloor characterization approaches, particularly through helping to better constrain the relationship of high-frequency backscatter to seafloor properties. It will also provide critical information on the relationship of *in situ* properties to those made in the laboratory as well as those extracted remotely from the inversion of seismic (Chirp Sonar) data.

TRANSITIONS

None yet.

RELATED PROJECTS

Uncertainty DRI, Mine Burial DRI

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